Title: Peak and Annual Average Energy Efficiency Penalty of Optimized Air-Cooled Condenser on 515 MW Fossil Fuel-Fired Utility Boiler

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Abstract

This paper examines the peak (90 °F dry bulb) and annual average heat rate penalty of a 515 MW pulverized coal-fired boiler equipped with air-cooled condenser (ACC) at a north central U.S. site location, as well as the cost implications of using ACC. The basecase scenario used for the comparison is a conventional wet tower assuming a 12 °F approach temperature. The basecase wet tower is compared to ACC with no spray enhancement for three ACC cases: 1) a conservative design with "initial temperature difference – ITD" of 35 °F, 2) a mid-range design with an ITD of 40 °F, and 3) an economic design with an ITD of 44 °F. The ITD design conditions for these three cases band a condenser backpressure range from 4 inches Hg to 5 inches Hg at the site design temperature of 90 °F. The ITD design points for the three ACC cases used in this analysis reflect a representative range of ACC designs based on current bids being submitted by ACC manufacturers.

Results for the 40 °F ITD ACC case indicate that the heat rate penalty at rated boiler load at the design condition of 90 °F is approximately 3.6 percent relative to a conventional wet tower. Heat rate penalty is approximately 2 percent on an annual average basis. For the 35 °F ITD ACC case the heat rate penalty at design conditions is 2.8 percent relative to a conventional wet tower. The annual average heat rate penalty is approximately 1.5 percent. The total auxiliary power demand for the ACC options is slightly higher than the wet tower basecase at design conditions, and slightly lower on an annual average basis.

The use of a 40 °F ITD ACC in place of the least-cost wet tower basecase would increase project CAPEX by approximately 6 to 7 percent. The use of a 35 °F ITD ACC would

increase project CAPEX by approximately 7 to 8 percent. The CAPEX percentage increase is somewhat less if a plume-abated tower is necessary at the site and serves as the basecase. The use of a 40 ^{o}F ITD ACC in place of a plume-abated FRP wet tower would increase project CAPEX by approximately 4 to 6 percent.

Background - Dry Cooling and Coal-Fired Powerplants

ACCs have been used on large coal-fired power plants for over 25 years. The 330 MW Wyodak coal-fired powerplant in Wyoming has successfully operated with an ACC for over 25 years. The largest ACC-equipped coal-fired power plant in the world, the 4,000 MW Matimba plant in South Africa, has been operating successfully for nearly 15 years. The Millmerran Power Project in Australia, consisting of two ACC-equipped 420 MW pulverized coal-fired units with condenser heat rejection rates in the range of the condenser heat rejection rate of the 515 MW unit evaluated in this paper, have been operational since 2002. A 300 MW pulverized coal plant currently undergoing permitting in New Mexico, the Mustang Project, will voluntarily incorporate ACC into the plant design to minimize plant water use. A 36 MW pulverized coal unit in Iowa, Cedar Falls Utilities Streeter Station Unit 7, was retrofit with dry cooling in 1995 due to highway safety concerns caused by the wet tower plume in winter. The use of dry cooling on pulverized coal-fired power plants is well established.

Basis of Design Comparison

The proposed 515 MW (rated net output, maximum 530 MW) Weston Unit 4 supercritical pulverized coal (SCPC) project is the basis for this case study. This project was proposed in 2003 by the Wisconsin Public Service Company (WPSC) for a central Wisconsin location using a conventional wet tower cooling system. The performance characteristics of Weston Unit 4 project are detailed in the Final Environmental Impact Statement (FEIS) prepared by WPSC. This is a publicly available document accessible on the Public Service Commission of Wisconsin website.

A cooling tower consisting of twelve (12) cells and a cooling water circulation rate of 250,650 gallons per minute (gpm) is proposed for Weston Unit 4. The rated wet tower heat rejection duty is 2,177 MMBtu/hr. The design approach temperature of the wet tower is 12 °F. The tower will evaporate approximately 4,750,000 gallons per day of river water, and produce approximately 475,000 gallons per day of cooling tower blowdown, on an annual average basis.

Steam Pro™ and Steam Master™ utility boiler design software are used to carry out the comparative heat rate analysis of the wet tower basecase and ACC alternatives. Steam Pro™ changes the design of the equipment with each new input. Steam Master™ takes a selected Steam Pro™ run and "fixes" all inputs to permit analysis of off-design cases.

The initial objective was to model a basecase 530 MW (maximum net output) wet-cooled SCPC unit in Steam Pro™ that matched the characteristics and heat rate described in the FEIS for the proposed Weston Unit 4. This objective was achieved. The wet-cooled basecase unit developed in Steam Pro™, after recalculating using Steam Master™, has a calculated a net plant heat rate (HHV) of 9,741 Btu/kWh at the design ambient air temperature of 90 °F, compared to a published net plant heat rate of 9,760 Btu/kWh in the WPSC FEIS for Weston Unit 4 at 530 MW.

Case Study Goals

The goals of this case study are to: 1) determine the peak and average heat rate penalty of ACC relative to the basic wet tower design for three ACC design cases with ITDs of 35 °F, 40 °F, and 44 °F, 2) determine the change in auxiliary power demand for each option, and 3) estimate the increase in project capital cost associated with the ACC alternatives. The site averages approximately 40 hours per year at or above an ambient temperature of 90 °F. The ITD is the difference between the design ambient air temperature used for cooling, 90 °F in this case, and the steam condensation (saturation) temperature within the ACC. Specific case study goals included:

- Determine the plant heat rate penalty, number of cells, and auxiliary power demand for three ACC configurations to achieve condenser saturation temperatures of 125 ^{o}F (35 ^{o}F ITD), 130 ^{o}F (40 ^{o}F ITD), and 134 ^{o}F (44 ^{o}F ITD) at design conditions;
- Calculate heat rate penalty for each ACC case at 2/3 load across site temperature range;
- Calculate the total plant auxiliary power demand for each cooling option;
- Estimate the additional capital cost of the ACC options relative to the wet tower basecase.

Site Temperature and Wet Bulb Data

The proposed project site is located in central Wisconsin. Weather data for Madison, Wisconsin was used by the project proponent to size the wet cooling tower included in the project basecase. The wet tower was sized to achieve a 12 ^{o}F approach temperature[1] at the summer 1 percent condition of 90 ^{o}F dry bulb and 76 ^{o}F wet bulb. Madison, Wisconsin temperature data was also used to size the ACC options. The annual temperature distribution data[2] for Madison is shown in Table 1.

Table 1. Madison, Wisconsin Annual Temperature Distribution Data

Temperature (^{o}F)	Hours per year in temperature range	Percentage of total hours per year at or above temperature range (%)
$\geq$ 90	42	0.48
85-89.9	75	1.34
80-84.9	290	4.65
75-79.9	391	9.11
70-74.9	585	15.79
65-69.9	593	22.56
60-64.9	829	32.02
55-59.9	749	40.57
50-54.9	629	47.75
45-49.9	534	53.85

[1] Cooling tower approach temperature: difference between the cooling water temperature leaving the cooling tower (lowest cooling water temperature achieved) and the wet bulb air temperature.

[2] Kjelgaard, M., *Engineering Weather Data*, McGraw-Hill, 2001, p. 534.

40-44.9	449	58.97
35-39.9	709	67.07
30-34.9	911	77.47
25-29.9	589	84.19
20-24.9	380	88.53
-20 - 19.9	1,005	100.00

Heat Rate Penalty of ACC

The peak and annual average heat rate penalties calculated for the 35 °F, 40 °F, and 44 °F ITD ACC configurations analyzed in this case study are shown in Table 2. For the 40 °F ITD case, the heat rate penalty at the design ambient temperature of 90 °F at full load is 3.6 percent, while the annual average heat rate penalty is approximately 2 percent. The heat rate penalty for the 35 °F ITD case at the design ambient temperature of 90 °F at full load is 2.8 percent, while the annual average heat rate penalty is approximately 1.5 percent. Sixty (60) cells would be required to achieve an ITD of 40 °F using an ACC fan diameter of 34 feet. Fan diameter of 36 feet may also be specified. A total of 54 ACC cells would be required to achieve an ITD of 40 °F using 36-foot diameter fans.

Table 2. Calculated Peak and Annual Average ACC Heat Rate Penalties

Case	ITD (°F)	Estimated annual average[a] heat rate penalty (%)	Peak heat rate penalty (%)	Fan diameter (feet)	Number of ACC cells
1	35	~1.5[b]	2.8	34 36	66 60
2	40	~2[c]	3.6	34 36	60 54
3	44	~3[d]	4.4	34 36	54 48

a) Assumes average annual load is 2/3 of rated load per EPA 316(b) TDD Chapter 3 for New Facilities, p.3-10.
b) 35 °F ITD 2/3 load heat rate penalties: 1.0% at 23 °F, 1.2% at 45 °F, 1.7% at 67 °F.
c) 40 °F ITD 2/3 load heat rate penalties: 1.4% at 23 °F, 1.7% at 45 °F, 2.2% at 67 °F.
d) 44 °F ITD 2/3 load heat rate penalties: 2.4% at 23 °F, 2.7% at 45 °F, 3.1% at 67 °F.

The annual average heat rate penalty for each ACC case was estimated as shown in Table 3. The number of annual operating hours in each of four discrete temperature ranges was calculated from the temperature data in Table 1. The annual average heat rate penalty estimate assumes that Unit 4 will typically operate at approximately two-thirds of rated load, or a capacity factor of 0.67, over the course of a year.[3] The capacity factor in the highest temperature range was assumed to be 0.85 to reflect high use during hot summertime conditions. A capacity factor of 0.60 was assumed for the three lower temperature ranges. The mean heat rate penalty for each temperature range was calculated from the Steam Pro™ heat rate curves developed for full load and two-thirds load operating scenarios. The mean between the 90 °F full load heat rate penalty (3.6 percent) and the two-thirds load penalty at 67 °F (2.2 percent), 2.9 percent, was used to represent the composite heat rate penalty for the highest temperature range. This is a reasonable assumption given the mean temperature in the highest temperature range is 74 °F, and the unit will not be operating continuously at rated load when operating in the highest temperature range. The heat rate penalty at 74 °F and full load is 3.1 percent for the 40 °F ITD case. The heat rate penalty calculated at 23 °F was used for the lowest temperature range, as 23 °F was the lowest temperature point modeled.

Table 3. Procedure Used to Estimate Annual Average Heat Rate Penalty, 40 °F ITD Case

Site temp. range (oF)	Fraction of annual hours [H]	Capacity factor (CF)	CF weighting factor [CF_w]	Mean heat rate penalty [P_m]	Heat rate penalty contribution per temp. range [$H \times CF_w \times P_m$]
67 – 90+	.20	.85	1.4	2.9[a]	0.81
45-67	.34	.60	1.0	2.0	0.68
23-45	.33	.60	1.0	1.6	0.53
< 23	.13	.60	1.0	1.4	0.18
Estimated annual average heat rate penalty for 40 °F ITD case (%)					2.20

a) The mean heat rate penalty between the full load 90 °F operating point (3.6%) and 2/3 load at 67 oF (2.2%) is 2.9%. The full load heat rate penalty at 67 °F is also 2.9%.

[3] U.S. EPA Technical Development Document (TDD) for the Proposed Section 316(b) Phase I New Facilities Rule, *Chapter 3: Energy Penalties, Air Emissions, and Cooling Tower Side-Effects*, November 2001, pg. 3-10. Coal plants have average capacity of 69 percent, therefore use 67 percent load curves to determine energy penalty values.

By way of comparison, the EPA estimates a heat rate penalty for a Chicago area coal-fired utility boiler equipped with ACC of 8.4 percent (peak) and 5.9 percent (annual average) compared to the same unit equipped with closed-cycle wet cooling.[4]
The EPA used the ITDs from a handful of existing ACC-equipped coal-fired utility boilers and plotted this data against steam condenser backpressure to establish a "representative" ACC heat rate penalty for coal-fired utility boilers.[5] The ITDs at existing ACC-equipped coal plants included in the EPA analysis are generally much higher than the ITDs being specified for new coal plants. A current state-of-the-art ITD for coal-fired units is 40 ^{o}F, based on discussions with major ACC manufacturers. New units with ITD's in the range of 35 ^{o}F ITD are becoming more common.

In addition, the EPA compared the ACC data to plants with wet towers using a 10 ^{o}F design approach. As noted by the EPA, a 10 ^{o}F approach is considered a conservative wet tower design standard. It could be argued that the approach used by the EPA is an "apples-to-oranges" comparison that accentuates the ACC heat rate penalty by comparing non-conservative ACC designs to a conservative wet tower design.

As shown in Table 2, the 40 ^{o}F ITD ACC case has a heat rate penalty of 3.6 percent at rated load and 90 ^{o}F ambient temperature. The rated output of Weston Unit 4 is 515 MW. Weston Unit 4 is designed to fire three (3) percent more fuel than necessary, equivalent to a net output of 530 MW, to produce rated output.[6] Unit 4 would be able to produce at least 512 MW of its rated output of 515 MW at the 90 ^{o}F design condition using a 40 ^{o}F ITD ACC. The 90 ^{o}F design condition is reached approximately 40 hours per year.[7] At any temperature less than 90 ^{o}F Unit 4 will produce its full rated output of 515 MW using a 40 ^{o}F ITD ACC. A 35 ^{o}F ITD ACC has a calculated heat rate penalty

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[4] U.S. EPA Technical Development Document (TDD) for the Proposed Section 316(b) Phase I New Facilities Rule, *Chapter 3: Energy Penalties, Air Emissions, and Cooling Tower Side-Effects*, November 2001, p. 3-13, Tables 3-3 and 3-4.

[5] Ibid, p. 3-15.

[6] WPSC Weston Unit 4 July 2003 application, Volume II: Appendix E-1, Heat Balance

[7] Madison, Wisconsin annual temperature distribution

at the 90 ^{o}F design condition of 2.8 percent. Unit 4 would be able to produce its rated output of 515 MW at the 90 ^{o}F design condition using a 35 ^{o}F ITD ACC.

As noted, Unit 4 equipped with a 35 ^{o}F ITD ACC will maintain rated MW output across the entire spectrum of site climatic conditions. A 40 ^{o}F ITD ACC may exhibit a slight reduction in output, 512 MW versus 515 MW, at the 90 ^{o}F design condition. However, it is important to point out that the 90 ^{o}F design condition occurs for approximately 40 hours per year. There may be little financial incentive to spend additional millions on a 35 ^{o}F ITD ACC in order to produce an additional 100 to 200 MW-hr per year.

The total plant auxiliary power demand is slightly lower for any of the ACC options compared to the wet-cooled basecase on an annual average basis. At full load and the design ambient temperature of 90 ^{o}F the total plant auxiliary power demand is slightly higher, 1 to 2 percent, for the ACC options compared to the wet-cooled basecase. See Table 4. The modeled auxiliary power demand of a wet-cooled Unit 4 at rated load and 90 ^{o}F is 40.1 MW. The modeled auxiliary power demand for the wet tower basecase does not include auxiliary power demand associated with the Unit 4 raw cooling water clarifier system, as there was insufficient information in the WPSC FEIS to determine the auxiliary power demand of the system. The modeled auxiliary power demand of the 40 ^{o}F ITD ACC at the same conditions is 40.6 MW, or a 1 percent increase in the plantwide auxiliary power demand at design conditions. A comparison of the plantwide auxiliary power demand for the wet tower basecase and the three ACC options across the site temperature range is provided in Table 5.

Table 4. Comparison of Plantwide Auxiliary Power Demand for Rated Design Case, Wet-Cooled vs. 40 °F ITD ACC

Parameter	Plant Auxiliaries Power Demand (kW) at 530 MW net, 90 °F	
	Wet tower basecase	40 °F ITD ACC
Boiler primary air fan	1,537.6	1,592.8
Boiler secondary air fan	1,611.2	1,669.0
Boiler induced draft fan	6,477.2	6,708.3
Boiler gas recirculation fan	0.0	0.0
Boiler fuel delivery	6,334.5	6,562.1
Boiler forced circulation pump	0.0	0.0
Electrostatic precipitator (ESP)	2,066.5	2,140.8
Flue gas desulfurization (FGD)	4,024.9	4,238.8
Ash handling	578.6	599.4
Condenser circulation pump	5,152.5	0.0
Cooling tower fan/ACC fan	2,141.5	6,809.5
Condensate pump	1,281.0	1,330.8
Boiler feedwater booster pump(s)	0.0	0.0
Boiler feed pump	0.0	0.0
Boiler feed booster pump	577.0	597.5
FW heater drain pump(s)	286.7	276.2
Additional auxiliaries (from Steam Pro™ *Plant Equipment and Construction Estimate* software)	5,216.6	5,183.8
Miscelleneous plant auxiliaries	2,850.5	2,852.5
Constant auxiliary load	0.0	0.0
Calculated total auxiliaries	40,136.3	40,561.6

Table 5. Comparison of Wet- vs. Dry-Cooled Total Plantwide Auxiliary Power Demand Across Site Temperature Range

Design Condition	Plant Total Auxiliary Power (MW)			
	23 °F, 67% load	45 °F, 67% load	67 °F, 67% load	90 °F, 100% load
conventional wet tower	27.2	27.6	28.3	40.1
44 °F ITD	25.4	26.7	28.3	40.4
40 °F ITD	24.2	25.0	27.2	40.6
35 °F ITD	25.1	26.3	28.0	41.1

ACC Cost Implications

WPSC estimates a Weston Unit 4 project cost of $752 million using a standard wet cooling tower.[8] The cooling tower material of construction is not identified in the table listing cooling tower operating parameters in the Weston Unit 4 application.[9] For this reason the least-cost material of construction, Douglas Fir, is assumed. A 10 percent increase in wet tower cost is estimated by the EPA if a fiberglass reinforced plastic (FRP) tower is selected over the least-cost Douglas Fir alternative.[10] The $752 million cost includes the cost of a clarifier system to be added to treat river water that will be used in Unit 4, as well as the cost of modifications to an existing water intake structure increase pump capacity to meet the peak cooling water requirements.

The ACC equipment cost assumes a large ACC cell that can accommodate 34-foot or 36-foot diameter fans. The equipment cost of this cell is approximately $600,000, based on Millmerran coal-fired project in Australia.[11] The installed cost for this project, using union labor and excluding civil work, is $970,000 per cell. The total installed cost including civil work is approximately $1,000,000/cell.[12] A full noise abatement package would increase this cost by up to $100,000/cell.

The equipment cost for a 40 °F ITD ACC for Weston Unit 4, consisting of 60 cells without special noise abatement features, would be $36 million. The installed cost for the Unit 4 ACC system without special noise abatement refinements

[8] Pre-filed direct testimony by Jerry Terrell on behalf of WPSC, April 30, 2004, Application of Wisconsin Public Service Corporation for Authority to Construct a 500MW Generating Unit at its Existing Weston Generating Station, before Public Service Commission of Wisconsin, Docket 6690-CE-187.

[9] Weston Unit 4 Certificate of Public Convenience and Necessity, filed with Public Service Commission of Wisconsin, Sept. 23, 2003. See *Cooling Tower Modeling Report*, p. 11.

[10] Economic and Engineering Analyses of the Proposed 316(b) New Facility Rule, Appendix A: Detailed Information on Technologies/Development of Unit Costs, Table A-4, Relative Cost Factors for Various Cooling Tower Types, pg. AppA-14.

[11] E-mail communication from F. Ortega, GEA PCS, May 12, 2005. Costs based on Millmerran Project, Australia.

[12] The cost of civil work was not available prior to the paper submittal deadline, though this cost is anticipated to be small relative to other ACC cost elements.

would be $60 million. The cost increment of a 35 °F ITD ACC relative to a 40 °F ITD ACC would be approximately 10 percent, or an installed cost of $66 million.

The U.S. EPA estimates the installed cost of a 204,000 gpm Douglas Fir (least-cost) conventional wet tower designed for a 10 °F approach temperature at $9 million in 1999 dollars.[13] The design cooling tower flowrate for Weston Unit 4 is 250,000 gpm. Scaling the 204,000 gpm cost estimate to the 250,000 gpm flowrate gives a projected cost for a basic wet tower of $11 million.[14]

However, the Weston Unit 4 wet tower is designed for a 12 °F approach temperature, which would result in a wet tower approximately 15 percent smaller than a unit designed for a 10 °F approach temperature.[15] The adjusted EPA installed cost estimate for a Douglas Fir wet tower with a 250,000 gpm flowrate and 12 °F approach is $10 million. Use of FRP adds 10 percent to the Douglas Fir wet tower basecase. An FRP conventional tower for Unit 4 has an estimated installed cost of $11 million.

EPA estimates a cost of $27.5 million for a 204,000 gpm plume-abated FRP wet tower designed for a 10 °F approach.[16] This is equivalent to a cost of $32 million for a 250,000 gpm plume-abated tower with a 10 °F approach, and $28 million for a 250,000 gpm flowrate and 12 °F approach (1999 dollars).

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[13] Economic and Engineering Analyses of the Proposed 316(b) New Facility Rule, Appendix A: Detailed Information on Technologies/Development of Unit Costs, Table A-7, Capital Costs of Douglas Fir Cooling Towers with Special Environmental Impact Mitigations Features (delta 10 °F) (1999 dollars), August 2000, pg. AppA-19.

[14] Ibid. EPA uses a scaling factor of ~0.8 in to estimate the cost of larger size cooling towers [$x = 0.8$, $(S_2/S_1)^x$]. The 0.8 scaling factor is used to calculate estimated cooling tower costs for the Weston Unit 4 design cooling water flowrate of 250,000 gpm (S_2) compared to the largest wet tower listed in the EPA document at 204,000 gpm (S_1).

[15] Marley, *Cooling Tower Performance – Basic Theory and Practice* (technical primer), June 1986. See Figure 6, p. 4.

[16] Economic and Engineering Analyses of the Proposed 316(b) New Facility Rule, Appendix A: Detailed Information on Technologies/Development of Unit Costs, Table A-4, Relative Cost Factors for Various Cooling Tower Types, pg. AppA-14. Mid-point cost multiplier for plume abatement tower is 2.75 relative to conventional wet tower.

Use of ACC eliminates the need for the surface condenser required in the basecase wet tower system. Steam Pro™ estimates a $3.7 million equipment cost for the surface condenser. An installed surface condenser cost of $5 million is assumed in this cost analysis. This condenser capital cost is subtracted from the CAPEX calculated for each ACC case. Table 6a summarizes the estimated CAPEX of the project depending on the cooling system specified using published EPA wet tower cost estimating methodology and ACC vendor equipment and installation cost estimates. Table 6b summarizes the Steam Pro™ CAPEX estimates for the wet tower basecase and the ACC alternatives studied.

Table 6a. Comparison of Project Cost of Wet- and Dry-Cooled Options, Using EPA Wet Tower Cost Data and ACC Vendor Cost Data to Estimate CAPEX of Options

Cooling System	Total Project Capital Expenditure - CAPEX ($ millions)	Increase in CAPEX (%)
Douglas Fir conventional wet tower	752[a]	basecase
Plume-abated FRP wet tower	770	2.4
44 °F ITD ACC	791	5.2
40 °F ITD ACC	797	6.0
35 °F ITD ACC	803	6.8

a) Project CAPEX estimated by project applicant.

Table 6b. Steam Pro™ Estimate of CAPEX for Wet- and Dry-Cooled Options

Cooling System	CAPEX ($ millions)	Cooling system equipment cost ($ millions)	Increase in CAPEX (%)
Least cost wet tower	885[a]	9[b]	basecase
Plume-abated FRP wet tower	894	12	1.0
44 °F ITD ACC	942	28	6.4
40 °F ITD ACC	948	31	7.1
35 °F ITD ACC	954	34.5	7.8

a) Wisconsin labor rates used in calculating CAPEX.
b) Cost includes surface condenser, cooling tower, condenser circulating water pump, and cold water basin.

There is a significant difference in the CAPEX cost between the two cost approaches summarized in Tables 6a and 6b. This is not unexpected, as the Steam Pro™ model was optimized in this exercise to match the published thermal performance of Weston Unit 4. No default cost assumptions were modified, other than to specify the project location to ensure appropriate labor rate assumptions were used to calculate CAPEX. Steam Pro™

does make explicit that default cost values must be optimized using site-specific information to refine the Steam Pro™ CAPEX estimate. The principal value of the Steam Pro™ CAPEX cost estimates shown in Table 6b is to provide guidance on the relative cost increase of the project if ACC is utilized.

The Steam Pro™ model also provides cost estimates for individual pieces of equipment. The Steam Pro™ Douglas Fir wet tower equipment cost of $9 million is similar to the EPA installed cost estimate of $10 million for a Douglas Fir wet tower. The EPA also indicates that wet tower installation is assumed to be 80 percent of equipment cost.[17] Applying the EPA installation cost assumption to the Steam Pro™ wet tower equipment cost would result in a wet tower installed cost of over $16 million. Clearly the EPA wet tower cost estimate is significantly lower than the Steam Pro™ estimate.

The EPA cost methodology indicates a significantly higher cost premium for an FRP plume-abatement wet tower relative to the cost premium calculated by Steam Pro™. The FRP plume-abatement tower would add 2.4 percent to CAPEX using the EPA methodology, while Steam Pro™ estimates only a 1 percent increase in CAPEX for this upgrade.

The ACC equipment cost generated by Steam Pro™ is 10-15 percent lower than the equipment cost estimate provided by a leading ACC vendor. However, the Steam Pro™ default ACC installation cost assumptions result in a significantly higher installation cost than the cost calculated using the union labor cost estimate provided by the ACC vendor. The end result is CAPEX increments for ACC that are in relatively close agreement, 6.0 percent and 7.1 percent for the 40 ^{o}F ITD ACC, between the two cost estimating approaches summarized in Tables 6a and 6b.

[17] Ibid. Table A-5, footnote (1).

Conclusions

Results for the 40 ^{o}F ITD ACC case indicate that the heat rate penalty at rated boiler load at the design condition of 90 ^{o}F is 3.6 percent relative to a conventional wet tower. The heat rate penalty is approximately 2 percent on an annual average basis assuming an annual average load of 67 percent. For the 35 ^{o}F ITD ACC case the heat rate penalty at design conditions is 2.8 percent relative to a conventional wet tower. The annual average heat rate penalty is approximately 1.5 percent. The total auxiliary power demand and losses for the ACC options are slightly higher than the wet tower basecase at design conditions, and slightly lower on an annual average basis.

The use of a 40 ^{o}F ITD ACC in place of the least-cost wet tower basecase would increase project CAPEX by approximately 6 to 7 percent. The use of a 35 ^{o}F ITD ACC would increase project CAPEX by approximately 7 to 8 percent. The CAPEX percentage increase is somewhat less if a plume-abated tower is necessary at the site and serves as the basecase. The use of a 40 ^{o}F ITD ACC in place of a plume-abated FRP wet tower would increase project CAPEX by approximately 4 to 6 percent.